SECTION 6 - EVALUATION METHODS

Several methods used to resolve difficulties encountered during the measurement and analysis of aircraft noise data have been developed. Some of these procedures are applicable to all aircraft types whereas others have limited application to one or more. This section presents these evaluation methods and describes specific procedures which have been approved to deal with:

a) spectral irregularities which are not related to the aircraft noise sources;

b) ambient noise levels both acoustic and electrical;

c) the establishment and extension of data bases;

d) the use of inertial navigation systems for aeroplane flight path measurements;

e) integrated analysis of noise data;

f) computation of EPNL by the integrated method of adjustment; and

g) calculation of the speed of sound.

6.1 SPECTRAL IRREGULARITIES

Tone corrections are required for tones or irregularities in the spectra of aeroplane noise. Irregularities which occur in measured spectra due to interference effects caused by reflection of sound from the ground surface or by perturbations during the propagation of the noise from the aeroplane to the microphone need to be identified so that tone corrections are not applied to spectral characteristics which are not related to the aeroplane noise source. As specified in paragraph 4.3.1 of Appendix 2 of Annex 16, Volume 1, narrow band analysis is one recommended procedure for identifying these false tones. Other methods of identification that have been approved for use in certification are included in Appendix 2 of this manual. However, the effect of these spectral irregularities are not normally removed from data from propeller-driven aeroplanes or helicopters since they are difficult to differentiate from engine and propeller or rotor associated tones.

6.2 AMBIENT NOISE LEVELS

Ambient noise levels including background acoustic noise levels and electronic noise from measuring and analysis equipment can mask noise levels from aeroplanes over parts of the frequency range of interest for effective perceived noise level calculations. The effects of ambient noise may be removed by use of an approved procedure such as described in Appendix 3.

6.3 ESTABLISHMENT AND EXTENSION OF DATA BASES

6.3.1 Noise certification levels may be determined from a number of repeat noise measurements, at least six, at the same engine power (transmitted power for helicopters), height, speed and configuration at each of the reference noise measurement positions. The noise measurements are adjusted to reference conditions and the mean value and 90 per cent confidence interval obtained in accordance with Annex 16, Volume 1. As an alternative, aircraft may be flown over a range of noise correlating parameters (μ). In the case of aeroplanes the correlating parameter may be engine power setting and/or helical tip Mach number for propeller driven aeroplanes. For helicopters the parameter may be power setting, advancing blade tip Mach number, speed or any other agreed parameter. At least six flights are needed to establish the noise level versus the relevant correlating parameter relationship covering the range relevant to both the prototype and derived aircraft for each of the reference noise measurement sites. Provided that the 90 per cent confidence interval limit of not greater than ±1.5 EPNdB (or ±1.5 dBA as appropriate) is satisfied, as calculated in Appendix 1 of this manual, the noise certification levels may be obtained by entering the curve of noise level versus correlating parameter (μ) at the appropriate reference μ.

6.3.2 In some areas an extrapolation of the data field may be approved but care must be taken to ensure that the relative contributions of the component noise sources to the effective perceived noise level, sound exposure level or A-weighted noise level as appropriate, remains essentially unchanged and that a simple extrapolation of noise/correlating parameter curves can be made.

6.3.3 For propeller driven aeroplanes a change in propeller and/or powerplant may necessitate further flight tests to establish a revised noise-power-distance relationship.

6.4 TEST ENVIRONMENT CORRECTIONS

6.4.1 The atmospheric conditions specified in Annex 16, Volume 1, section 2.2.2(b), (c), (d) and (e) of Appendix 2 require the measurement of ambient air temperature and relative humidity profiles during noise certification tests, to ensure that the temperatures, relative humidities and corresponding atmospheric sound absorption coefficients do not deviate from the specified limits over the whole noise path between ground and aeroplane. Ordinarily, profile measurements are recorded by balloon, instrumented aeroplane, or other similar method during flight testing, in order to ensure that the criteria are met.

6.4.2 At the discretion of the certificating authority atmospheric profile measurements of ambient air temperature and relative humidity may be made by instruments mounted on the test aeroplane, and may be considered sufficient to determine compliance with the criteria specified in section 2.2.2(b), (c), (d) and (e) of Annex 16, Volume 1, Appendix 2.

6.5 INERTIAL NAVIGATION SYSTEMS FOR AEROPLANE FLIGHT PATH MEASUREMENT

6.5.1 Criteria for the measurement of aeroplane height and lateral position relative to the intended track are described in section 2.3 of Appendix 2 of Annex 16 Volume 1. This section indicates that the method used should be independent of normal flight instrumentation. Since the development of this requirement, other tracking systems (inertial navigation systems (INS) and microwave systems) which have a high degree of accuracy have been installed in aeroplanes and consequently have been accepted by several certificating authorities for use during noise certification. However, it is important that any inherent drift in the system is regularly determined and the system calibrated. For this purpose ground based cameras can be used to determine the position of an aeroplane relative to them both laterally and in terms of height. The calibration should be undertaken sufficiently frequently to retain the accuracy specification of the system.

6.5.2 The accuracy of such systems must be acceptable to the certificating authority.

6.6 COMPUTATION OF EPNL BY THE INTEGRATED METHOD OF ADJUSTMENT

6.6.1 Section 9.1 of Annex 16, Appendix 2 provides for the use of the "simplified" or "integrated" method for adjusting measured noise data to reference day conditions. The "integrated" procedure may be applied to measured data at the flyover, lateral, and approach noise measurement points. The "integrated" adjustment method consists of applying all data adjustments to each measured set of sound pressure levels obtained at 0.5 s intervals to identify equivalent reference average sound pressure levels which are used to compute EPNL's consistent with values which would be obtained under reference conditions. For complete acoustic consistency the adjustment is only applicable if evaluated for identical pairs of noise emission angle (θ) relative to the flight path and noise elevation angle (ψ) relative to the ground for both the measured (test) and corrected (reference) flight paths. While this requirement may be satisfactorily approximated for the flyover and approach noise measurements it can be shown that it is not possible to retain identical pairs of angles when lateral noise measurement adjustments are necessary. Therefore when lateral noise measurement adjustments are made by the "integrated" method, the geometric conditions, of identical noise emission angle should be maintained for test and reference flight paths while the corresponding differences between test and reference elevation angles should be minimised. The slight difference that will occur between test and reference elevation angle will have negligible effect on the corrected EPNL value.

6.6.2 This section describes an integrated adjustment method that is applicable for use when the aeroplane is operated at constant conditions (flight path and power) during the noise measurement period.

6.6.3 **Test aircraft position**

6.6.3.1 The "integrated" method for adjustment of measured noise-level data to reference conditions requires acoustic and aeroplane performance data at each 0.5 s time interval during the test flights. These data include aeroplane position relative to a three-dimensional (X, Y, Z) co-ordinate system, 1/3-octave-band sound pressure levels SPL(i,k), and time (t_k) at the midpoint of each averaging time period relative to a reference time. Additionally aeroplane performance parameters, the measurement microphone locations, and temperature and humidity is required for each flyover.

6.6.3.2 The aircraft height Z is measured above the reference X-Y plane, generally taken to be the ground plane, with the measurement microphone 1.2 m above this reference plane. The average test flight path is assumed to be a straight line (except when power reduction is used during the flyover measurement) and the time-correlated aeroplane-position data are used to determine time of overhead (t_{oh}), the test overhead height (h_{To})* , and the test minimum distance (d_{Tm}) from the test flight path to the microphone location (K(X_{TM}, Y_{TM}, Z_{TM})).

6.6.3.3 Using the test data directly or by geometric analysis of the relation between the average straight line flight path and the minimum distance line from K_T to R_T (X_{RT}, Y_{RT}, Z_{RT}) as shown in Figure 10 the minimum distance becomes:

$$d_{Tm} = \left[\left(X_{RT} - X_{TM}\right)^2 + \left(Y_{RT} - Y_{TM}\right)^2 + \left(Z_{RT} - Z_{TM}\right)^2\right]^{1/2}$$

Equation (1)

6.6.4 **Sound-propagation times and sound-emission angles**

6.6.4.1 The test sound propagation time (Δt_{pk}) is identified with the data record time (t_k), the noise emission time (t_{ek}), the aeroplane position (A_k) at time (t_{ak}), and the averaging time (t_{Av}) through the relationships:

$$t_k = t_{ak} - \tfrac{1}{2} t_{Av}.$$

Equation (2)

$$t_{ek} = t_k - \Delta t_{pk}$$

Equation (3)

*For emphasis the subscript "T" is used here for test conditions. Annex 16 uses un-subscripted symbols for test conditions.

$$\Delta t_{pk} = K_T Q_{ek} / c_T$$

Equation (4)

where c_T is the speed of sound for the average absolute temperature of the air between the surface (T_S) and the height of the aeroplane (T_A) (see Paragraph 6.7, where $T = (T_S + T_A)/2$).

6.6.4.2 Using the geometric relationships of Figure 11, the minimum distance from Equation (1), the test distance $Q_{ek}R$, and defining the time difference B equal to t_{Tm} - t_k yields the following expression for the test-flight-path sound-propagation times:

$$\Delta t_{Tpk} = \left[1 \big/ \left(c_T{}^2 - V_T{}^2\right)\right] \left\{ BV_T{}^2 + \left[\left(c_T{}^2 - V_T{}^2\right)\left(d_{Tm}\right)^2 + \left(Bc_T V_T\right)^2\right]^{1/2} \right\}$$

Equation (5)

where V_T is the average true air speed of the test aeroplane along the flight path.

6.6.4.3 Similarly the test sound-emission angle is defined as:

$$q_{ek} = \sin^{-1}\left(d_{Tm} / d_{Tpk}\right) \text{, or}$$

$$q_{ek} = \sin^{-1}\left[d_{Tm} \big/ \left(\Delta t_{Tpk}\right)\left(c_T\right)\right]$$

Equation (6)

6.6.5 **Aircraft reference flight path**

6.6.5.1 The geometry of the reference flight path is essentially similar to that shown in Figure 10, however, the following differences exist. The reference flight path is directly over the runway centerline (ie. Y_{DEV}=0). For the take off and approach flyovers, the measurement station is on the runway centerline (ie. Y_{Rr}=Y_{rM}); for lateral noise measurements, (Y_{Rr}-Y_{rM}) equals the reference lateral displacement of the measurement station.

Note (1): The subscript r is used to denote reference conditions.

Note (2): The reference microphone location (K_r) for flyover or lateral noise measurements is usually at the same co-ordinates as for the test location (K_T), ie. $\left(X_{TM}, Y_{TM}, Z_{TM}\right) = \left(X_{rM}, Y_{rM}, Z_{rM}\right)$.

6.6.5.2 The reference flight path may be geometrically specified relative to the reference microphone location (K_r) by using the measurement station lateral distance, the height overhead (h_{ro}) and the flight path inclination angle (γ_r). These values are equated to the minimum distance (d_{rm}) from K_r by the following:

$$d_{rm} = \left[h_{ro}{}^2 \cos^2 g_r + \left(Y_{Rr} - Y_{rM}\right)^2\right]^{1/2} \quad \text{or}$$

$$d_{rm} = \left[\left(X_{Rr} - X_{rM} \right)^2 + \left(Y_{Rr} - Y_{rM} \right)^2 + \left(Z_{Rr} - Z_{rM} \right)^2 \right]^{1/2}$$

Equation (7)

6.6.5.3 The basic acoustic assumption relating the test and reference flight conditions is that the three dimensional acoustic emission angles (θ_{ek} and θ_{erk}) for each test record time (t_k) and the corresponding reference time (t_{rk}) are equal. Using Equation (6) and this equality the test sound pressure levels, $SPL_T(i,k)$, for each of the i-th frequency bands, are adjusted for spherical spreading and atmospheric absorption over the acoustic path lengths by the equation:

$$SPL_r(i,rk) = SPL_T(i,k) - 20\log\left(d_{rpk} / d_{Tpk} \right) - \left[\left(a_{i0} \right) d_{rpk} - \left(a_i \right) d_{Tpi} \right]$$

Equation (8a)

where a_{i0} and a_i are the reference and test day sound attenuation coefficients respectively,

or, when the test and reference flight path minimum distances are used, by the equation:

$$SPL_r(i,rk) = SPL_T(i,k) - 20\log\left(d_{rm} / d_{Tm} \right) - \left[\left(a_{i0} \right) d_{rm} - \left(a_i \right) d_{Tm} \right] \operatorname{cosec} q_{ek}$$

Equation (8b)

6.6.6 **Time interval computation**

6.6.6.1 In addition to the above adjustments of the test data for spherical spreading and atmospheric absorption it is necessary to make an adjustment for the change in the time increment t_{rk} used in the computation of EPNL. Since the time increments are not equal to the 500 ms test measurement time increments when adjusted by the "integrated" method, successive aeroplane position reference times (t_{rk} and $t_{r(k+1)}$) occur after the time reference (t_{rek}) at the sound emission point (Figure 11). The average time increment to be used in the EPNL computation is:

$$dt_{rk} = \left[\Delta t_{rk} + \Delta t_{r(k-1)} \right] / 2$$

Equation (9)

where the reference time interval (Δt_{rk}) between data records is:

$$\Delta t_{rk} = t_{r(k+1)} - t_{rk}$$

and using the relationship between sample times, sound emission times, and sound propagation times the reference interval becomes:

$$\Delta t_{rk} = \left[t_{re(k+1)} - t_{rek} \right] + \left[\Delta t_{rp(k+1)} - \Delta t_{rpk} \right]$$

Equation (10)

6.6.6.2 This time interval reflects the time for the aeroplane to travel at test and reference speeds (V_T and V_r) from one sound emission point to the next and also the effect of differences between test and reference minimum distances (d_{rm} and d_{Tm}) as well as sound speeds (c_r and c_T). These factors are expressed explicitly by arranging Equation (10) as follows:

$$\Delta t_{rk} = \left(d_{rm}/d_{Tm}\right)\left\{\left(V_T/V_r\right)\left[0.5-\left(\Delta t_{Tp(k+1)} - \Delta t_{Tpk}\right)\right] + \left(c_T/c_r\right)\left(\Delta t_{Tp(k+1)} - \Delta t_{Tpk}\right)\right\}$$

Equation (11)

6.6.7 **Adjusted effective perceived noise level**

After the sound pressure levels have been adjusted using Equation (8) the tone corrections are calculated following section 4.3 of Appendix 2, Annex 16 and using the noy weighting and the procedure for calculating perceived noise level (Section 4.2, Appendix 2, Annex 16) the reference PNLT's are available for the times t_{r1} to t_{rn} which include the first and last 10 dB-down times. These values and the adjusted average time increment, Equation (9), are combined to compute the adjusted EPNL as follows:

$$\mathrm{EPNL} = 10\log\left[\left(1/\mathrm{T}_0\right)\sum_{k=1}^{n}\left(10^{0.1\mathrm{PNLT}_k}\right)\left(d\,\mathrm{t}_{rk}\right)\right]$$

where the reference time (T_0) is 10 s and the summation is started by setting $\Delta t_{r(1-1)} = \Delta t_{r(2-1)}$ so that $dt_{r(1-1)} = \Delta t_{r1}$. The summation is terminated by assuming $\Delta t_{rn} = \Delta t_{r(n-1)}$ giving $dt_{rn} = \Delta t_{rn} = \Delta t_{r(n-1)}$.

6.7 CALCULATION OF THE SPEED OF SOUND

For the purposes of noise certification the value of the speed of sound, c, shall be calculated from the equation taken from ISO 9613-1: 1993(E):

$$c = 343.2\left(T/T_0\right)^{1/2} \text{ metres / sec}$$

(i.e. $c = 1125.9\left(T/T_0\right)^{1/2}$ feet / sec)

where $T_0 = 293.15$ °K and *T* is the absolute ambient air temperature.